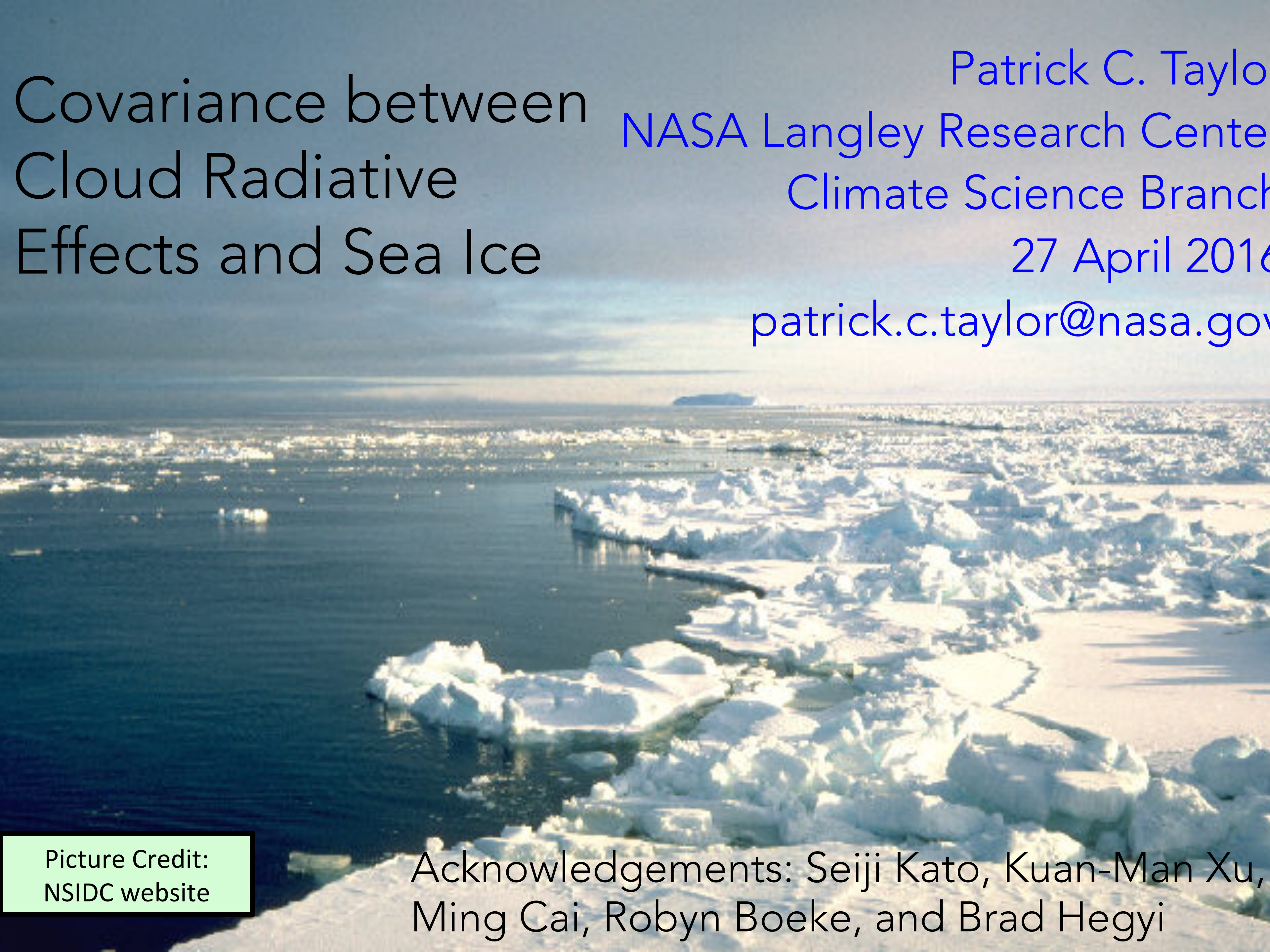

Covariance between Cloud Radiative Effects and Sea Ice

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27 April 2016
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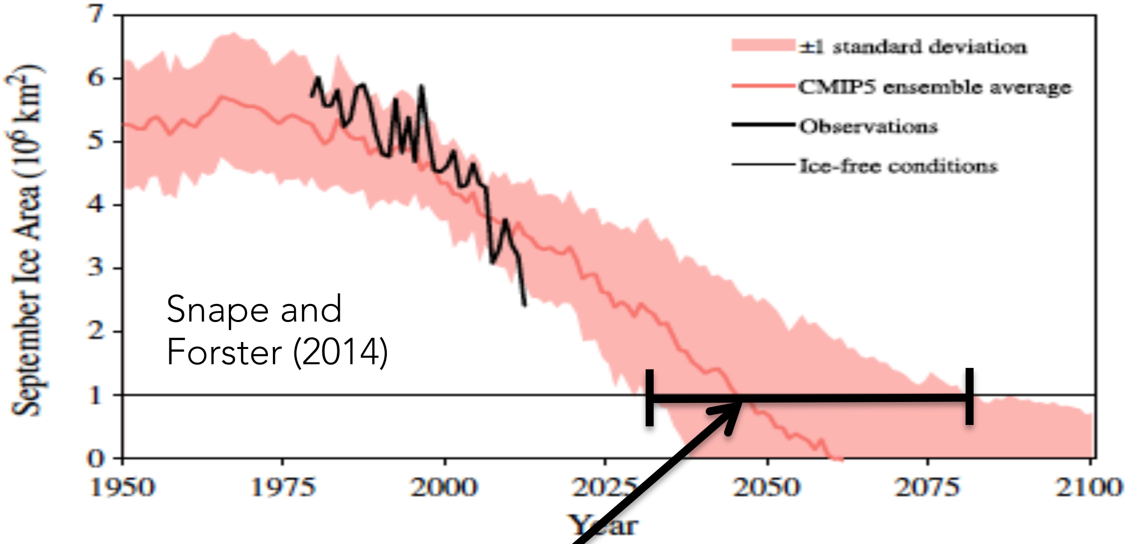
Picture Credit: NSIDC website

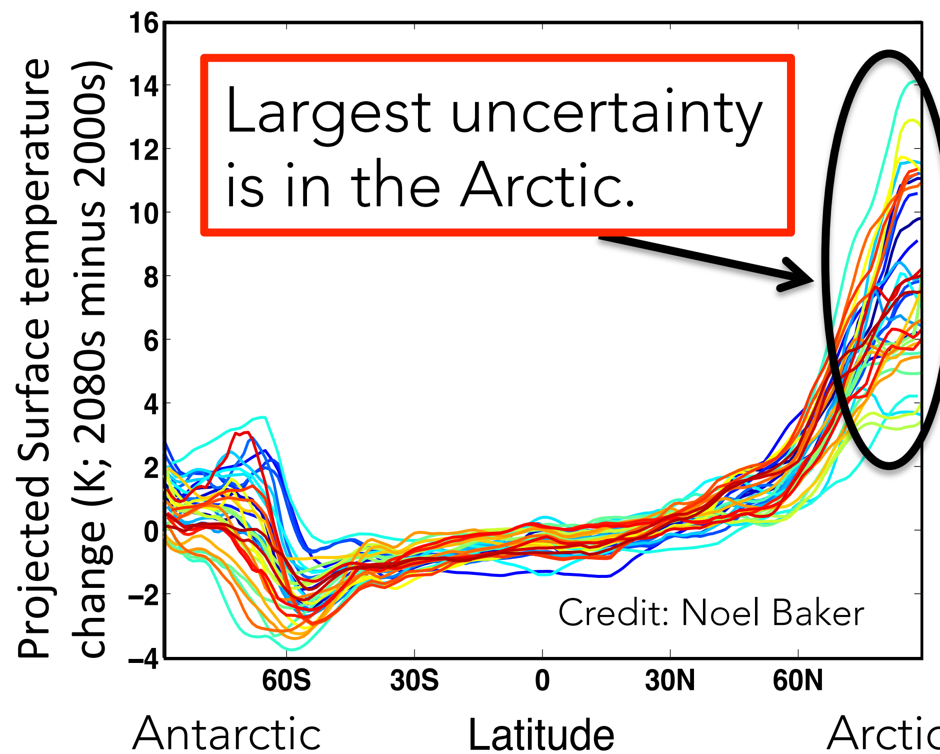
Acknowledgements: Seiji Kato, Kuan-Man Xu, Ming Cai, Robyn Boeke, and Brad Hegyi

Oh, the uncertainty…



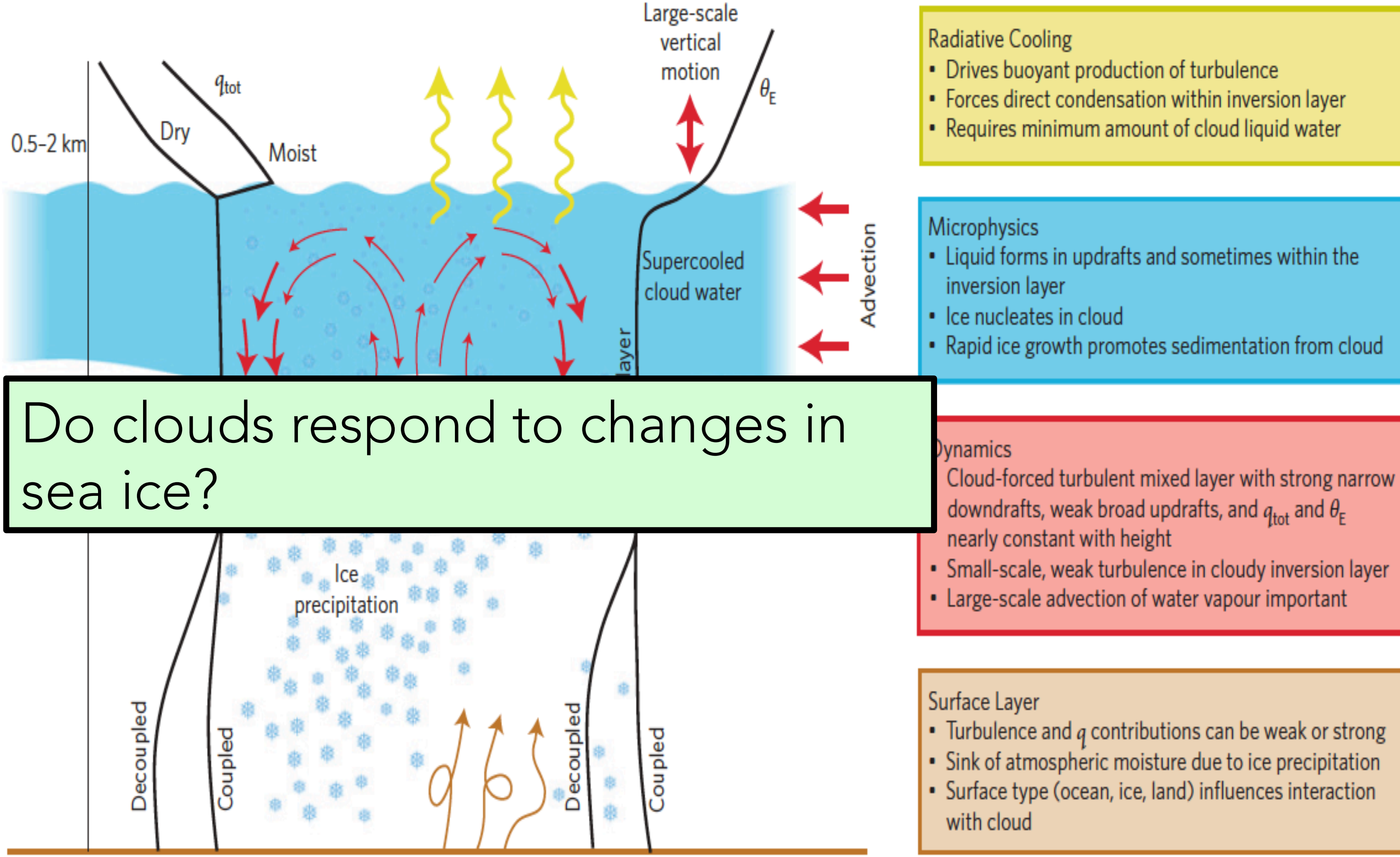
~50-year range in the projected first appearance of and ice-free Arctic

Projections of future Arctic sea ice decline and the timing of the first occurrence of a sea ice-free Arctic are very uncertain.



The large spread in climate model predictions of Arctic warming is attributed to model of sea ice melt and how it feeds back on the other components of the climate.

Arctic Low Cloud Processes

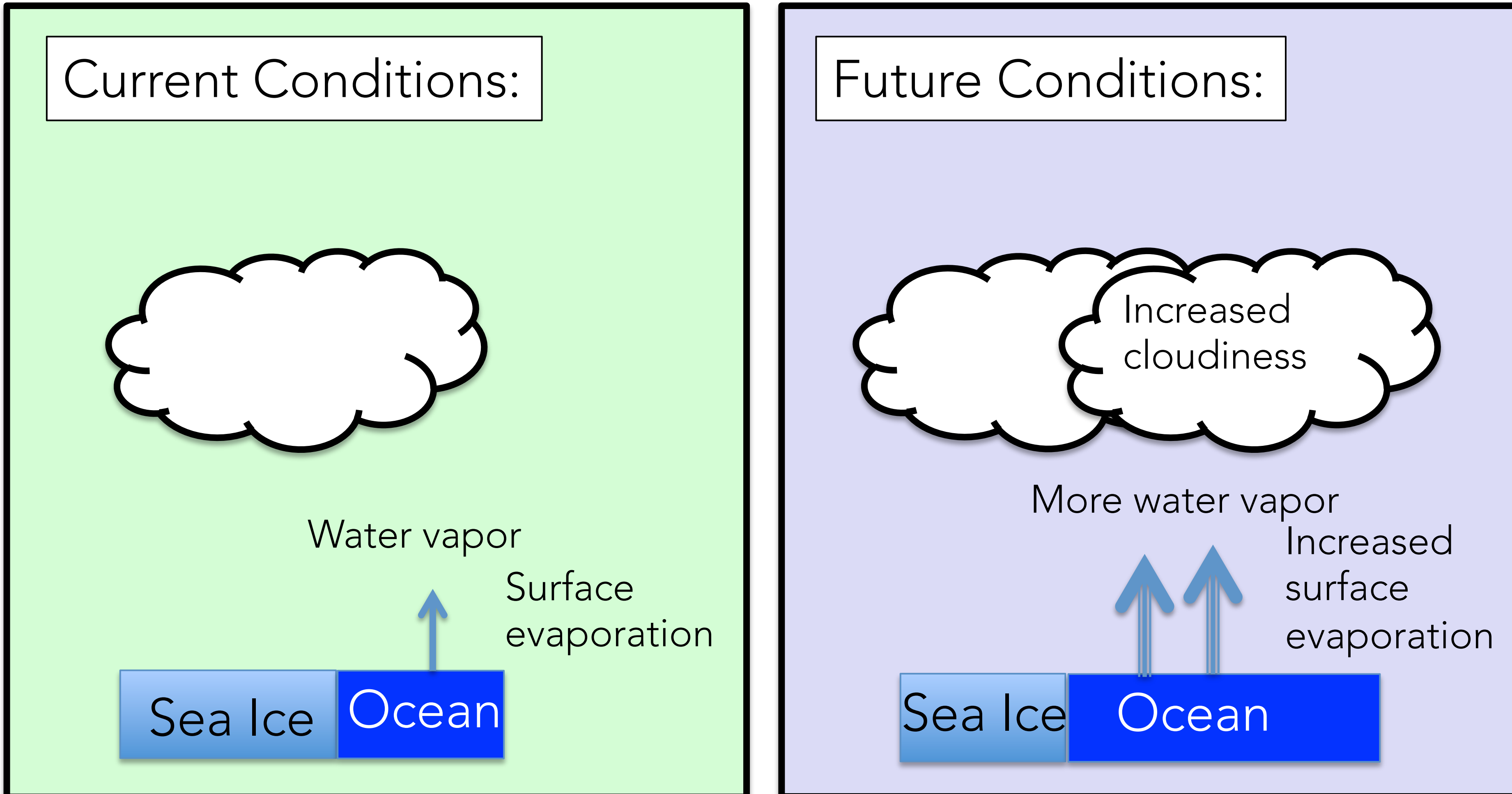


Do clouds respond to changes in sea ice?

The influence of the surface type on the cloud properties implies an interaction between clouds and sea ice that may significantly influence Arctic climate change.

Morrison et al. (2012; Nature Geoscience)

How might clouds respond to less sea ice in the Arctic?

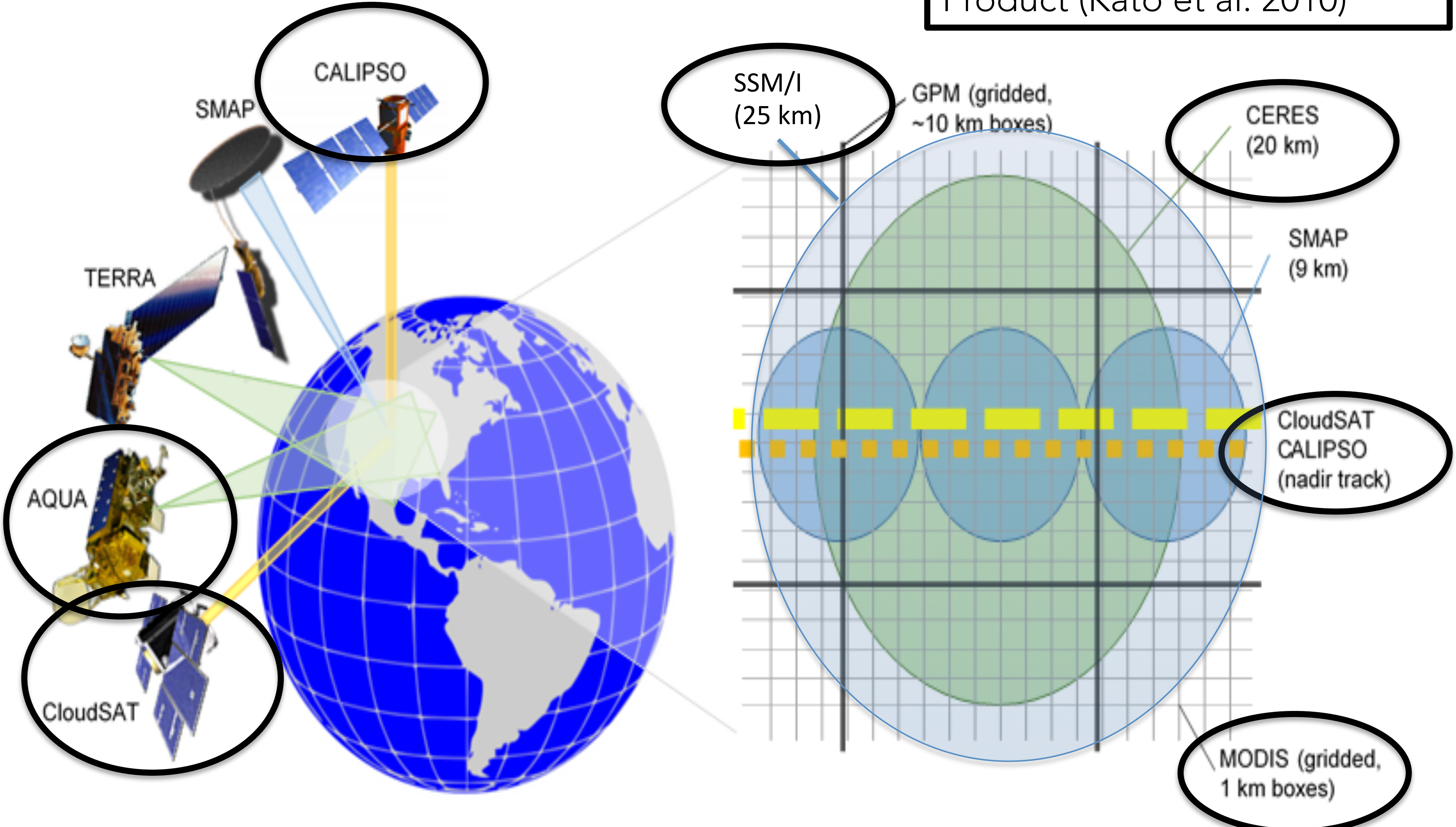


Science Question:
Do average cloud properties from instantaneous satellite observations vary with sea ice concentration?

That's the power of…

Data Fusion!?

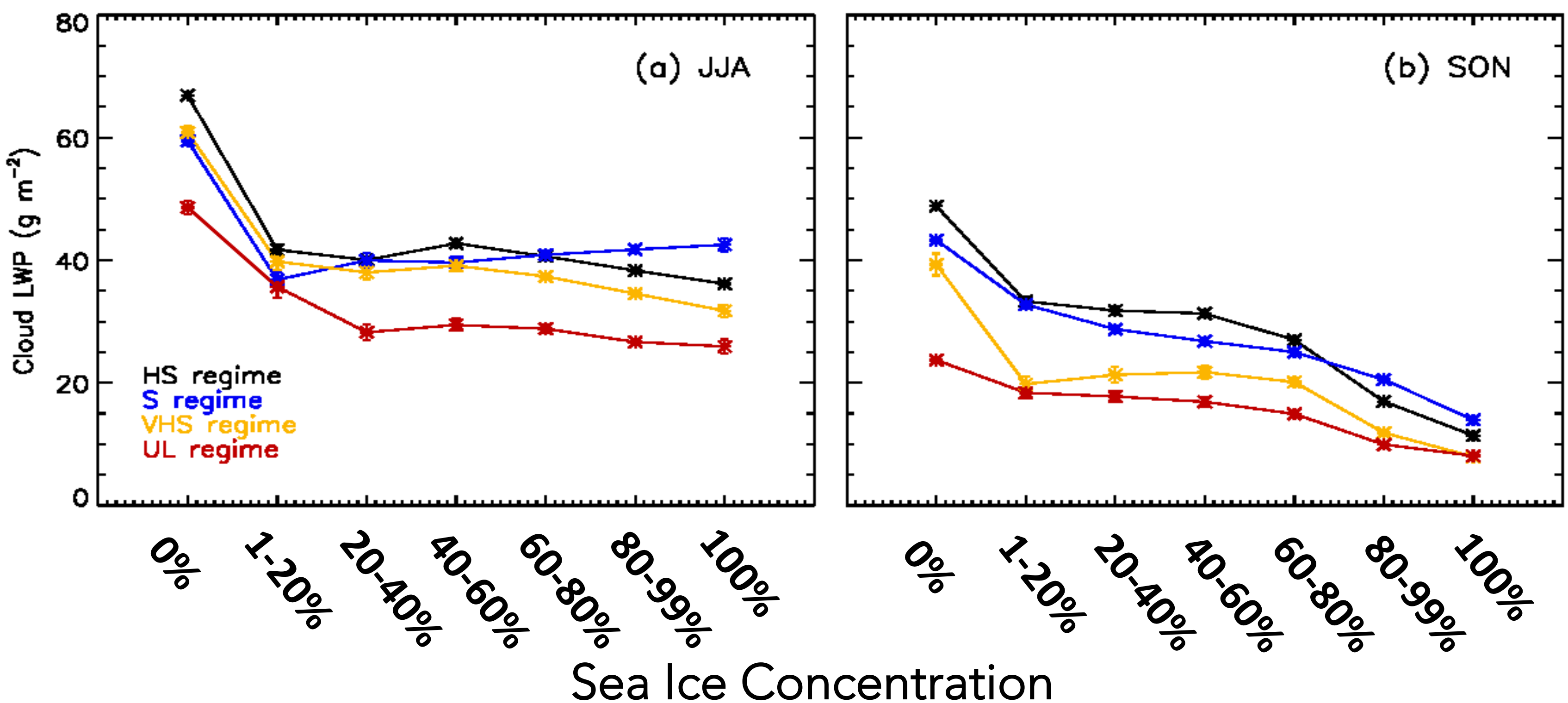
CALIPSO-CloudSAT-CERES MODIS (C3M) Merged Data Product (Kato et al. 2010)



Data are available from the NASA Langley ASDC: http://eosweb.larc.nasa.gov/

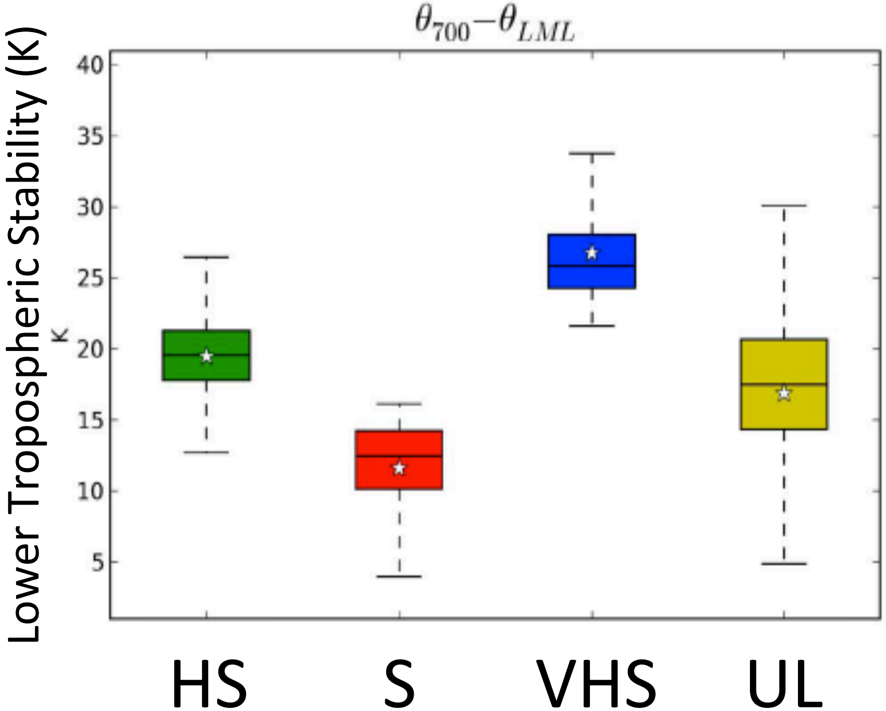
Compositing Methodology

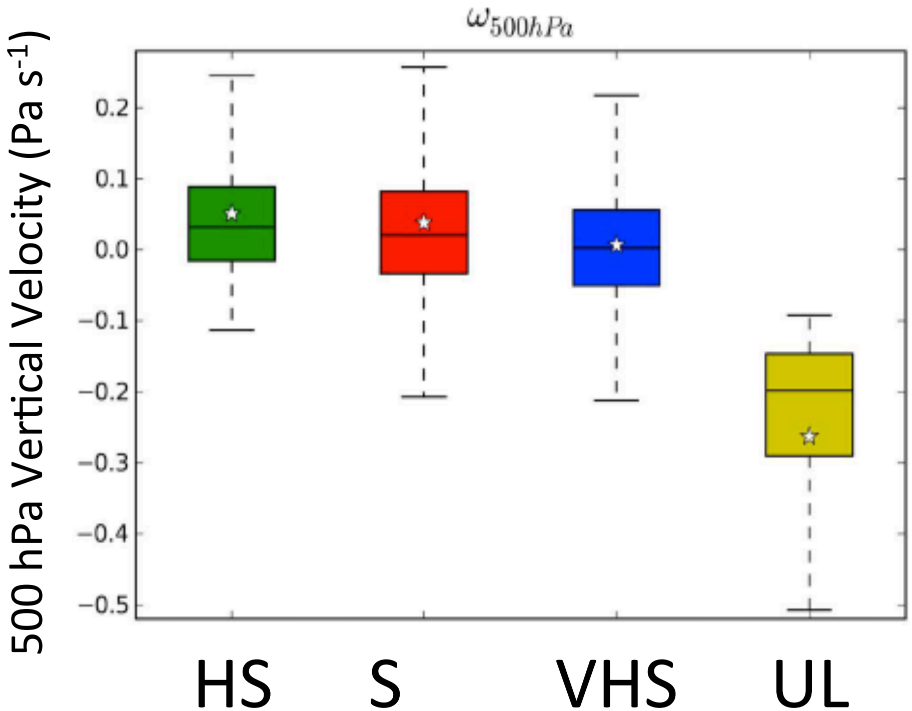
(1) Determine the Atmospheric Regime of each footprint using MERRA
(2) Determine the instantaneous sea ice concentration from SSM/I retrieval
(3) Average low cloud properties (cloud top < 3 km) within each atmosphere and sea ice concentration bin



The goal of the methodology is to retain as much process level information as possible by using satellite footprint level data, not monthly mean gridded.

Atmospheric Regimes (Barton et al. 2012)

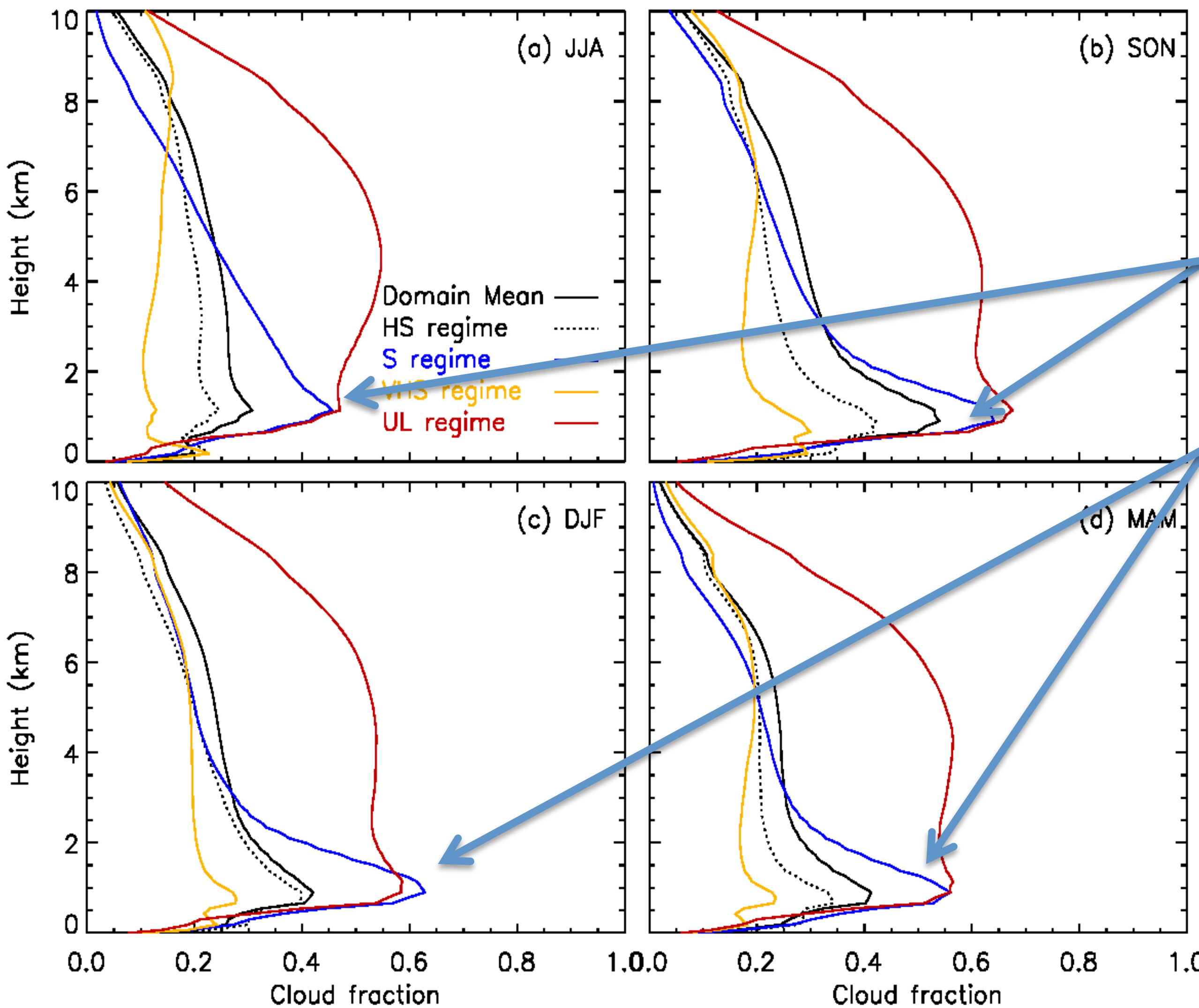




Atmospheric state regimes determined using K-means cluster analysis.

High Stability (HS): 16 K < LTS < 24 K
Stable (S): LTS < 16 K
Very High Stability (VHS): LTS > 24 K
Uplift (UL): ω_{500} < -0.1 Pa s^{-1}

Influence of Meteorological State

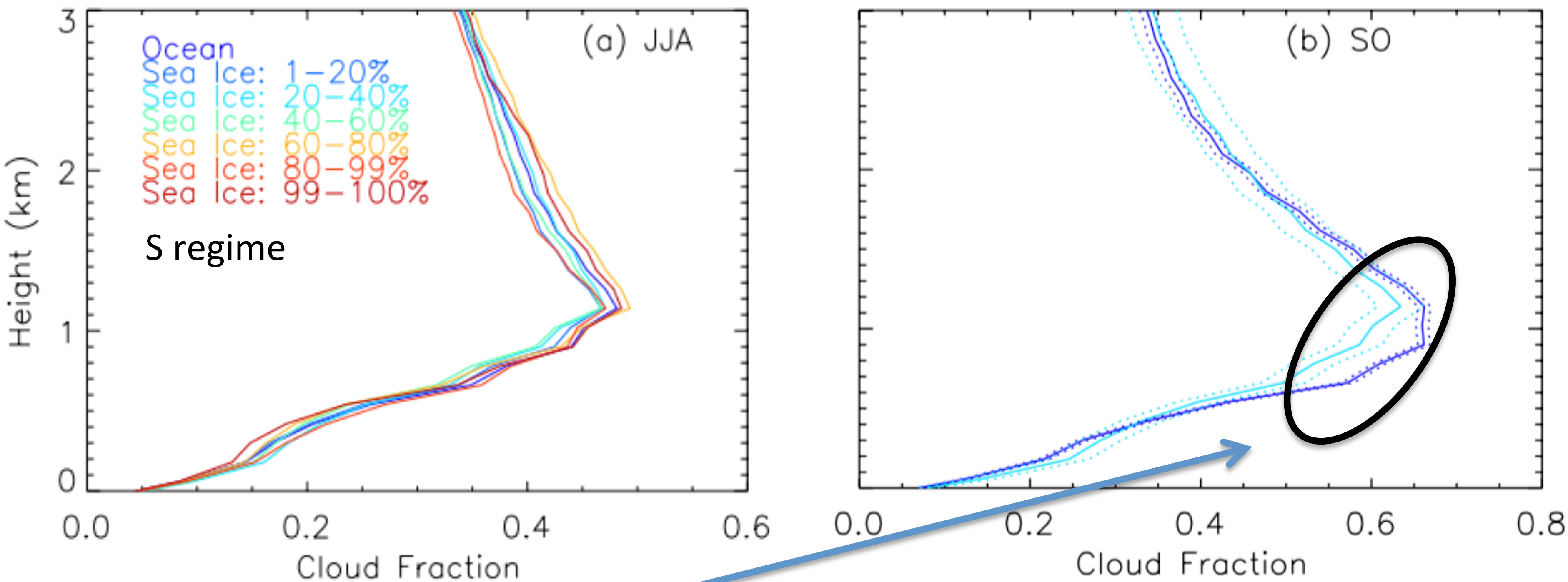


A decrease in the magnitude and height of the maximum cloud fraction is found as LTS increases.

Taylor et al. (JGR 2015)

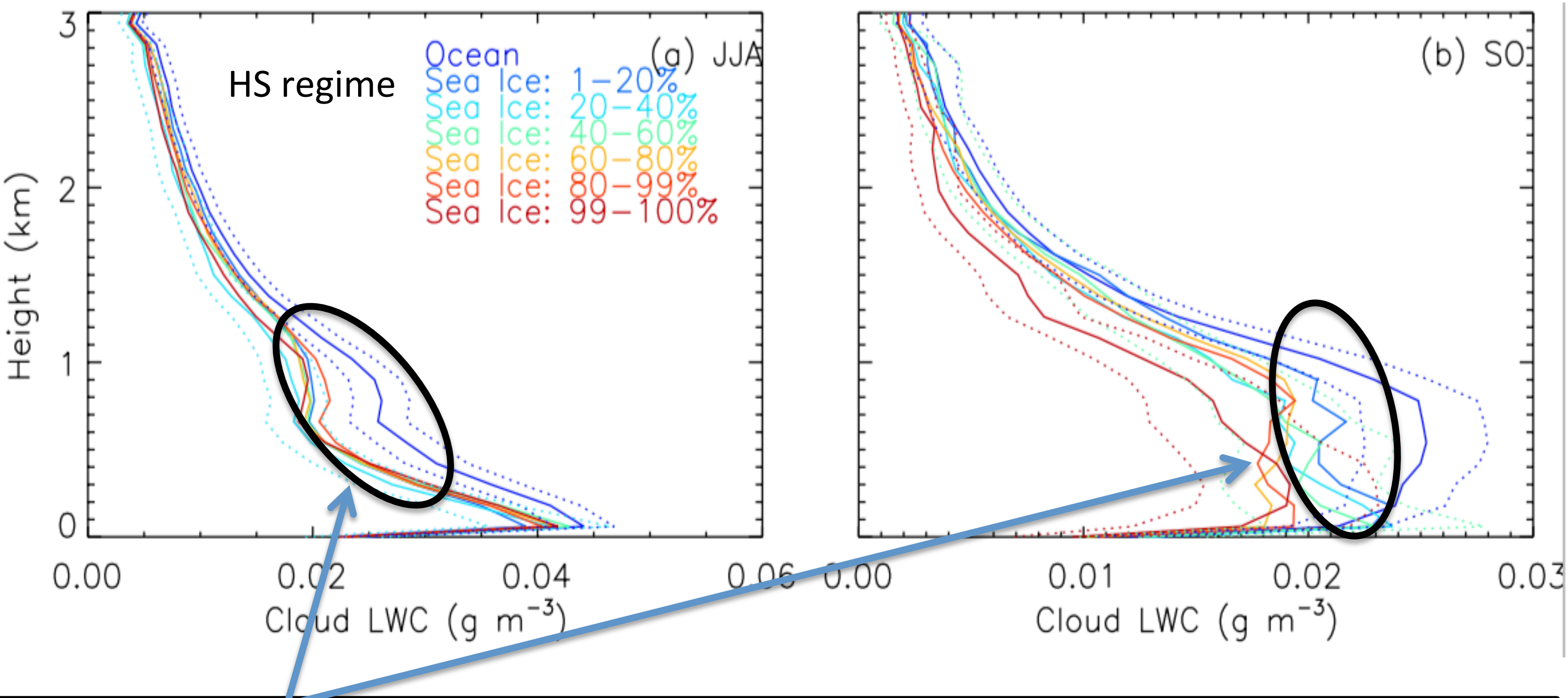
The results indicate that the characteristics of Arctic low clouds are primarily determined by the atmospheric conditions.

Results: Vertical Profile, CF



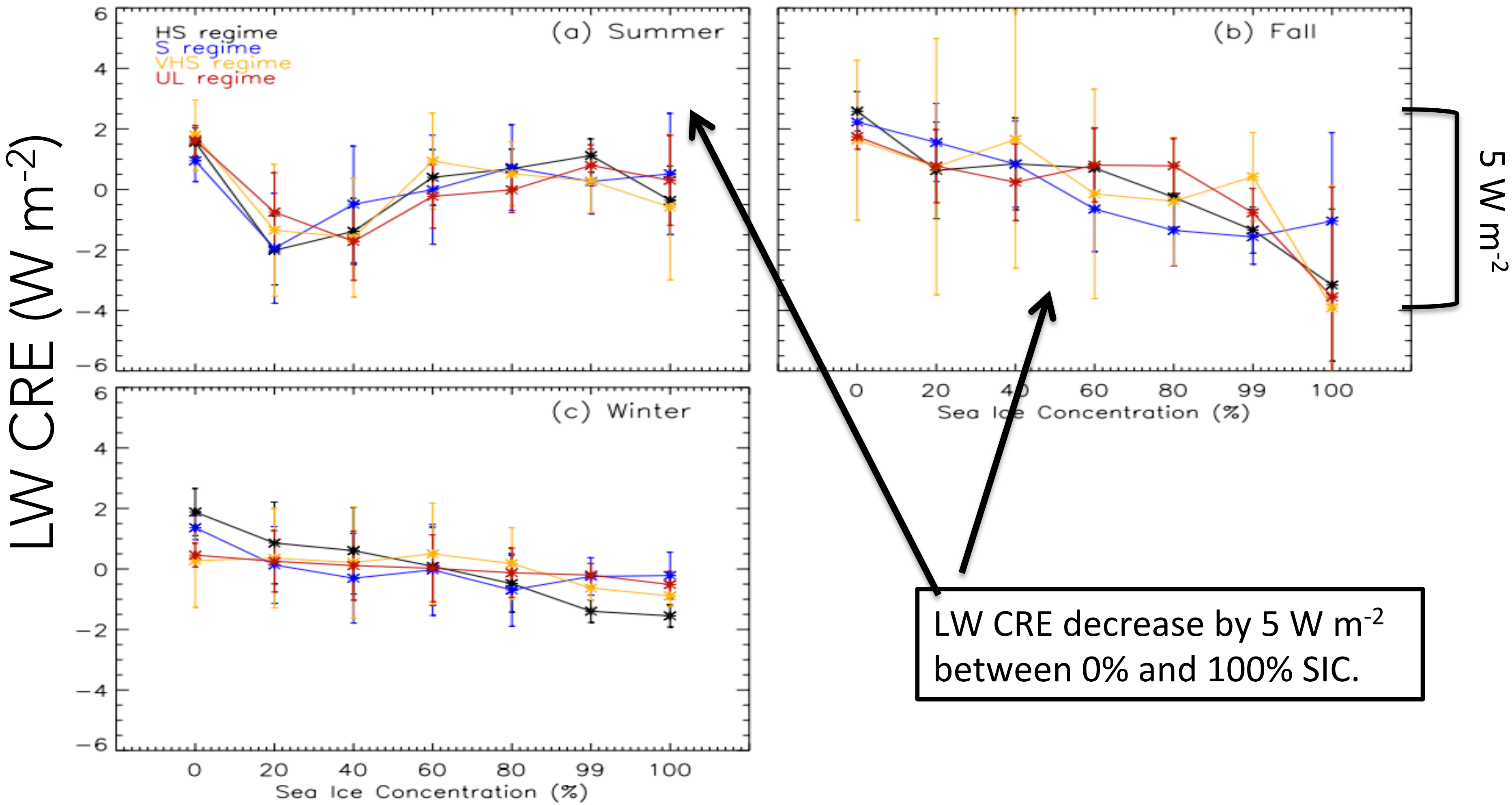
- General decrease in cloud fraction is found with increased sea ice concentration in in autumn, but no response in summer.
- Statistically significant differences at the 95% confidence interval are found at between 500 m and 1.2 km in autumn at 0% and 20-40% sea ice concentration.

Results: Vertical Profile, LWC



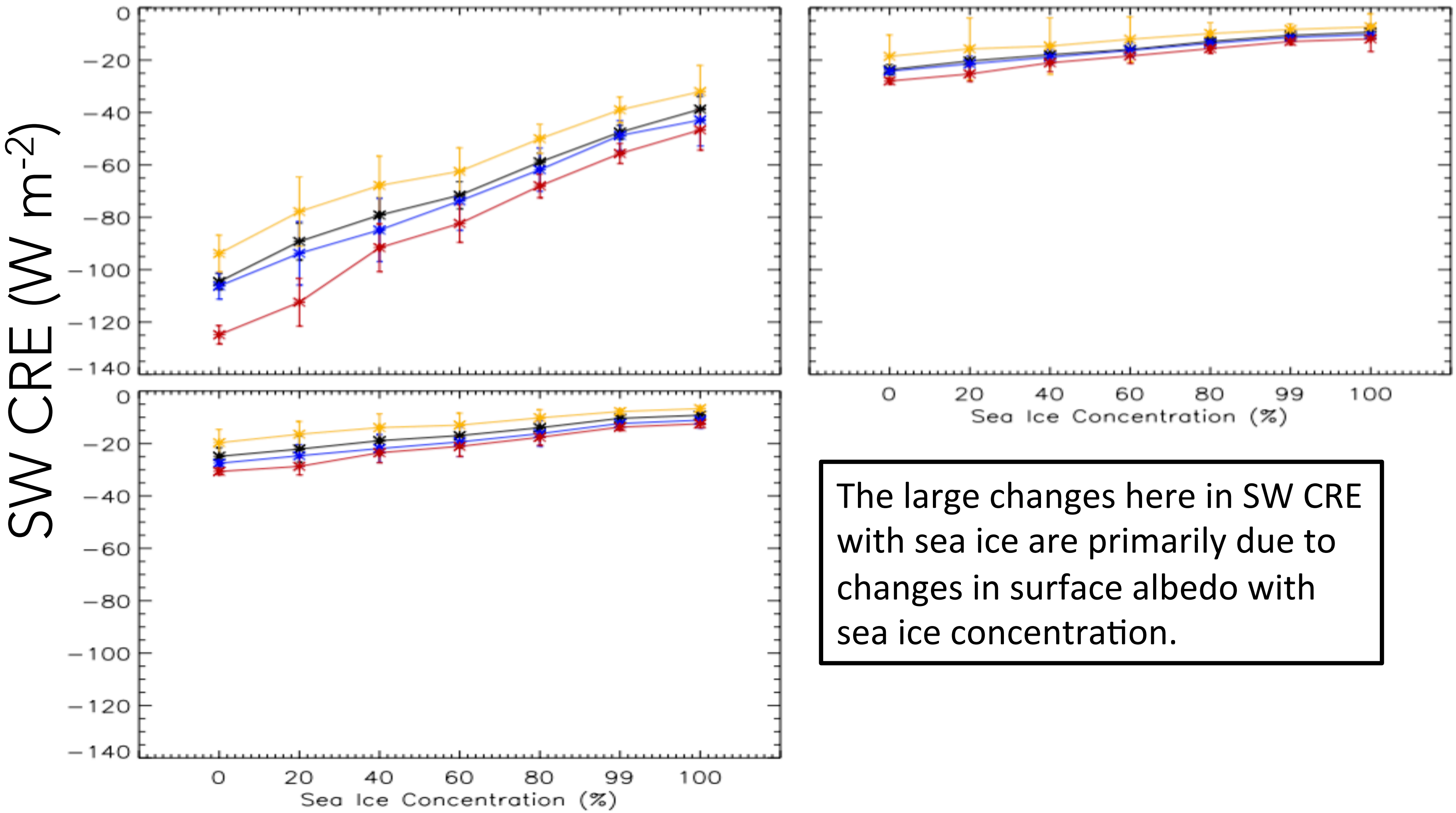
- General decrease in LWC is found with increased sea ice concentration in both summer and autumn.
- Statistically significant differences the LWC between 500 m and 1.2 km are found in summer and autumn at 0% and 20-40% sea ice concentration.

Results: Surface LW CRE



- General decrease in the LW CRE at the surface with increasing sea ice.
- Statistically significant differences at the 95% confidence interval are found in fall for the HS and S regimes.

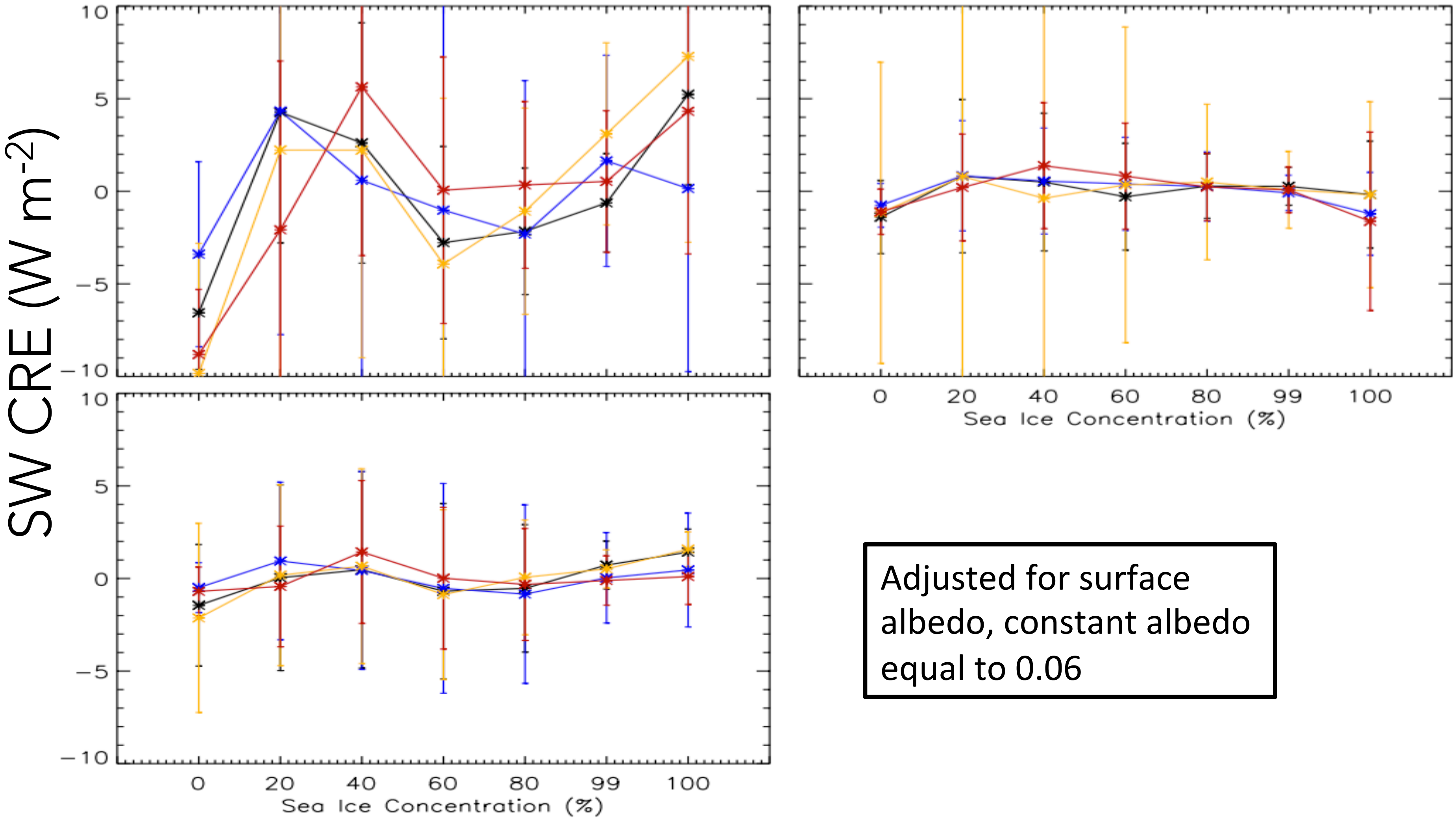
Results: Surface SW CRE



The large changes here in SW CRE with sea ice are primarily due to changes in surface albedo with sea ice concentration.

- Generally less negative SW CRE at the surface with increasing sea ice.
- Statistically significant differences at the 95% confidence interval are found in fall for the HS and S regimes.

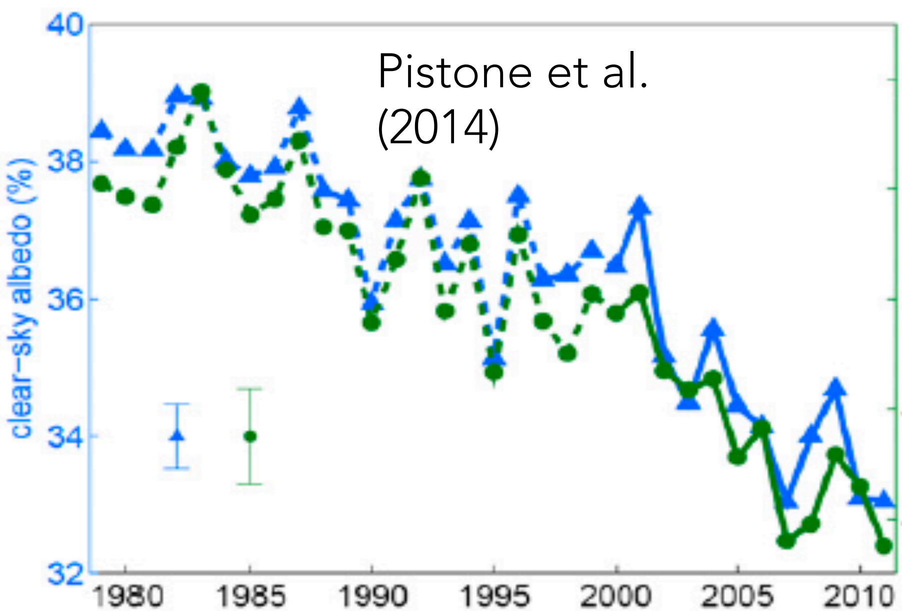
Results: Surface SW CRE



- Generally less negative SW CRE at the surface with increasing sea ice.
- No statistically significant differences around found at the 95% confidence interval.

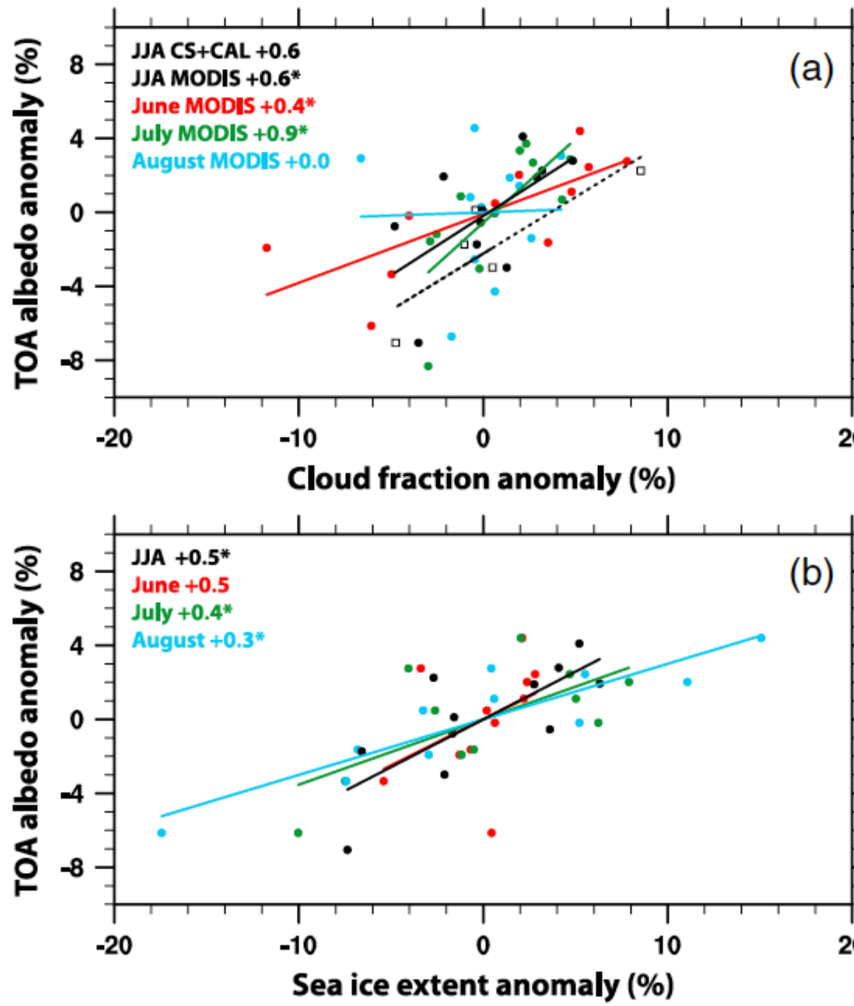
Implications of a weak cloud response to sea ice?

Other evidence for a weak cloud relationship with sea ice



Summertime albedo changes are determined by sea ice, not cloud.

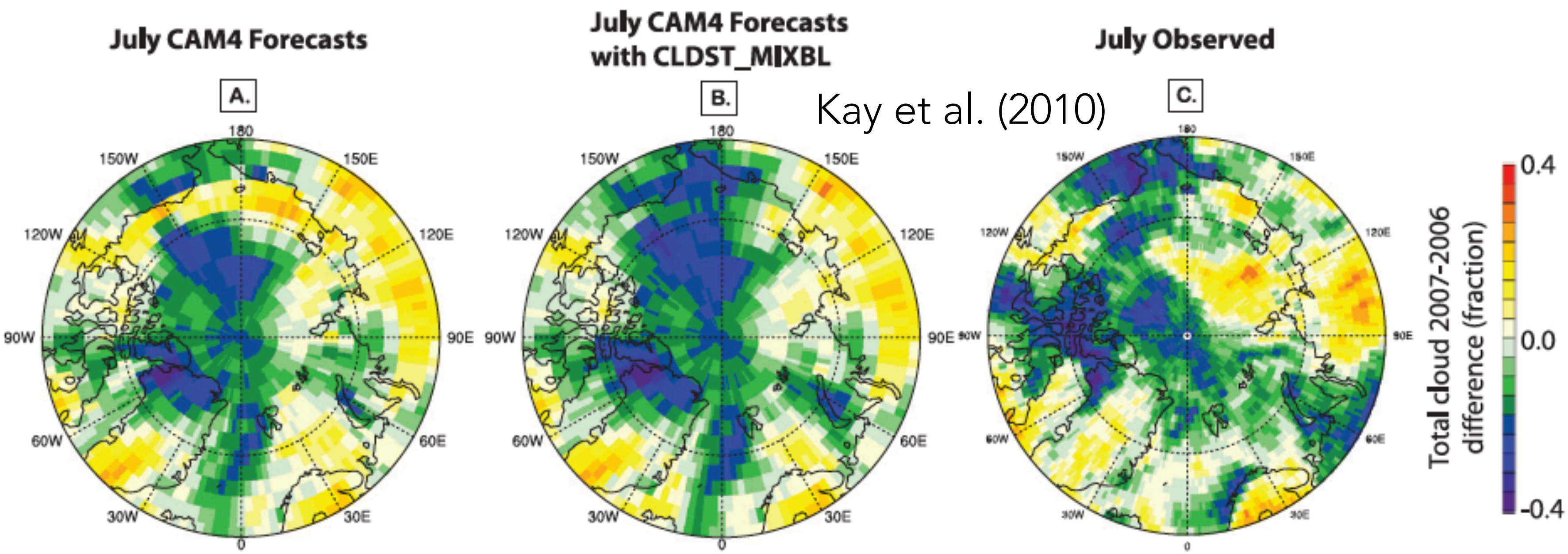
Late summer albedo changes are determined by sea ice, not cloud.



Kay and L'Ecuyer (2013)

Potential GCM Cloud-Sea Ice Interaction Bias

CAM4, and likely all GCMs using the same physics, simulates too strong a response of clouds to reductions in sea ice.



Kay et al. (2010)

This suggests a real potential that GCM projects of Arctic warming are biased low due to an unrealistic compensation of the surface albedo feedback by clouds.

Take away messages…

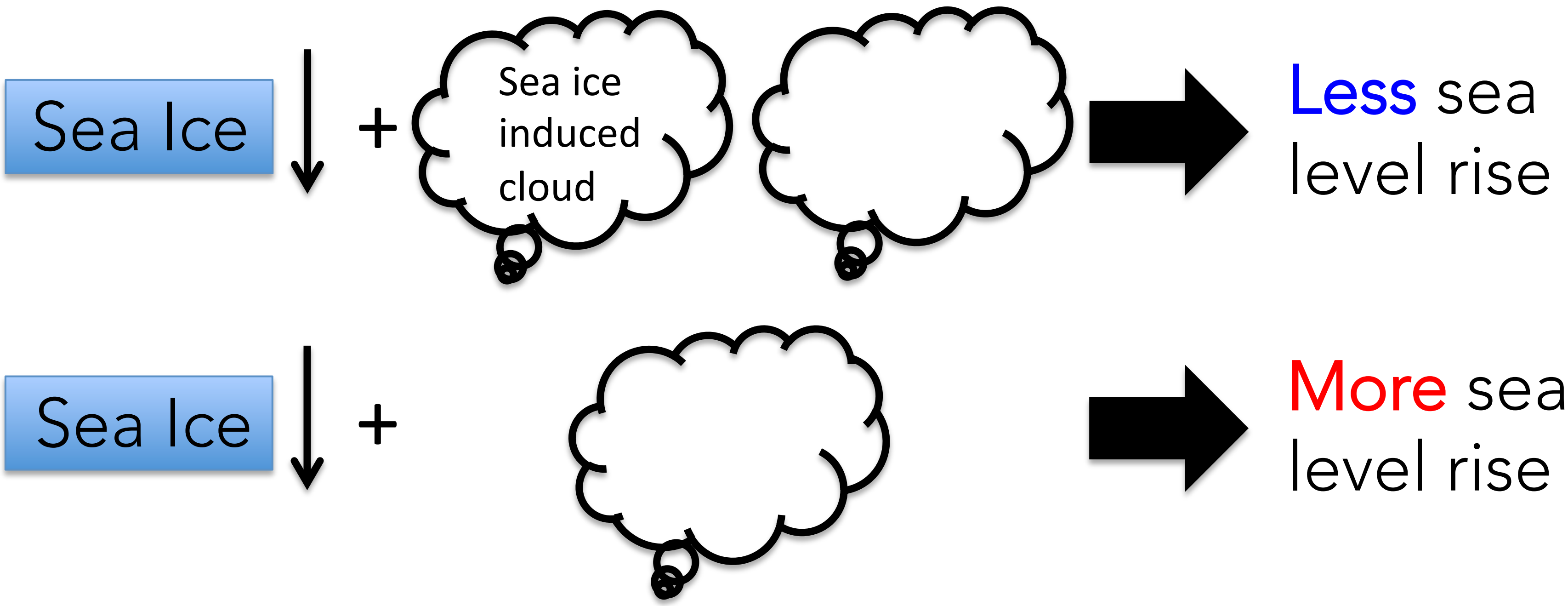
- Meteorological conditions are the primary driver of Arctic low cloud characteristics by at least an order of magnitude in most cases.
- Statistically significant covariance between cloud properties and sea ice are found in Autumn (agrees with previous work)
- A ~5 Wm^{-2} change in the LW CRE is found between open ocean and sea ice covered footprints. Indicating, a statistically significant influence of the cloud-sea ice interactions to the Arctic surface radiation budget in Autumn.


What happens in the Arctic doesn't stay in the Arctic.
It affects us all.
Questions?


What happens in the Arctic doesn't stay in the Arctic.
It affects us all.
Questions?

Working Hypothesis:

Arctic low clouds will increase in response to Arctic sea ice melt.



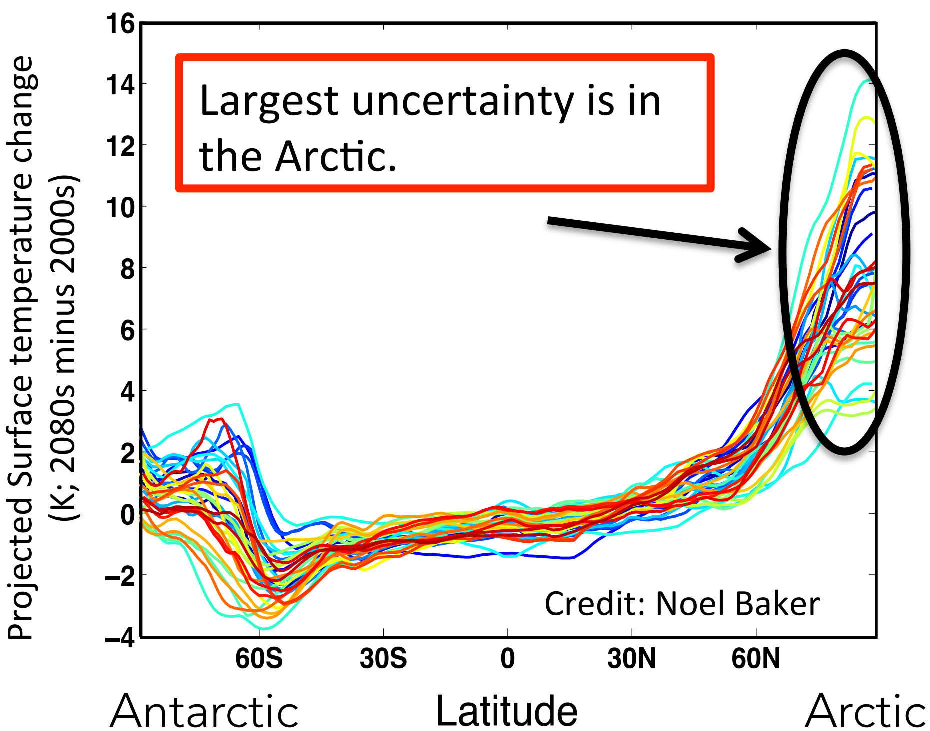
The results indicate a weak response of clouds to sea ice.

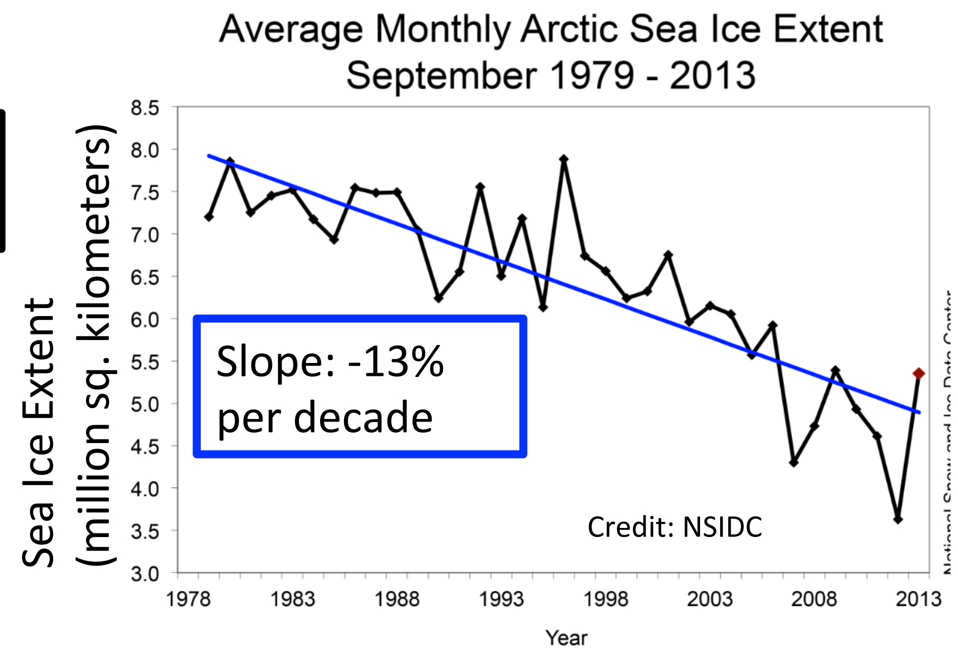
Implications: Climate models simulate too little Arctic warming and therefore sea level rise.

<u>Technical excellence punch line:</u>
Using novel data fusion techniques, this research reveals new and deeper understanding of climate by elucidating the mechanisms that control Arctic clouds.

Motivation

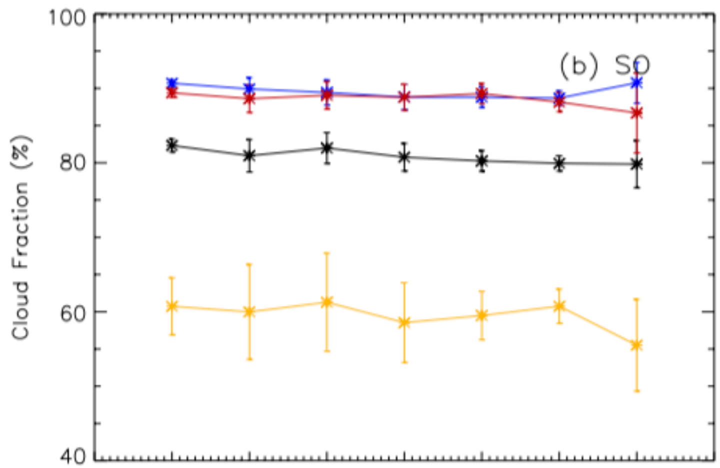
Rapid declines in September sea ice extent have been observed since 1979.

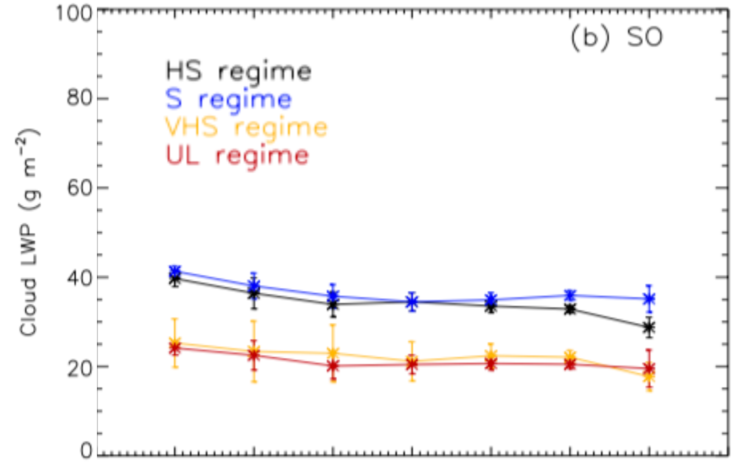




The large spread in climate model predictions of Arctic warming is attributed to feedback mechanisms related to sea ice melt, Arctic clouds, and circulation.

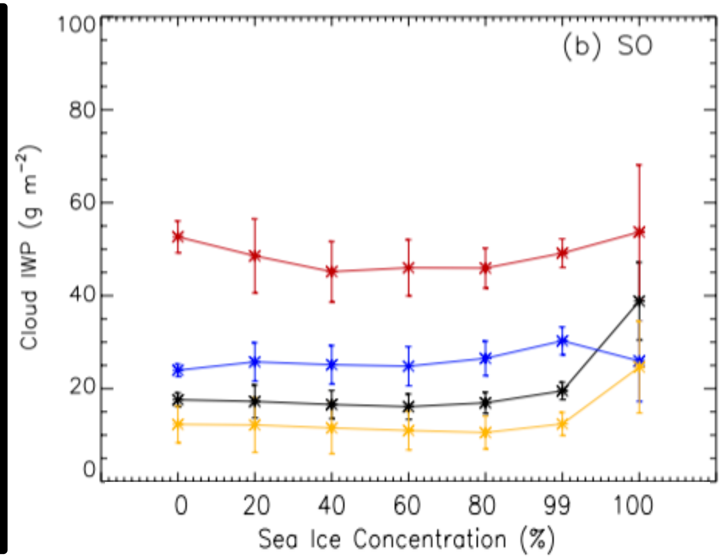
Results: Column Integrated





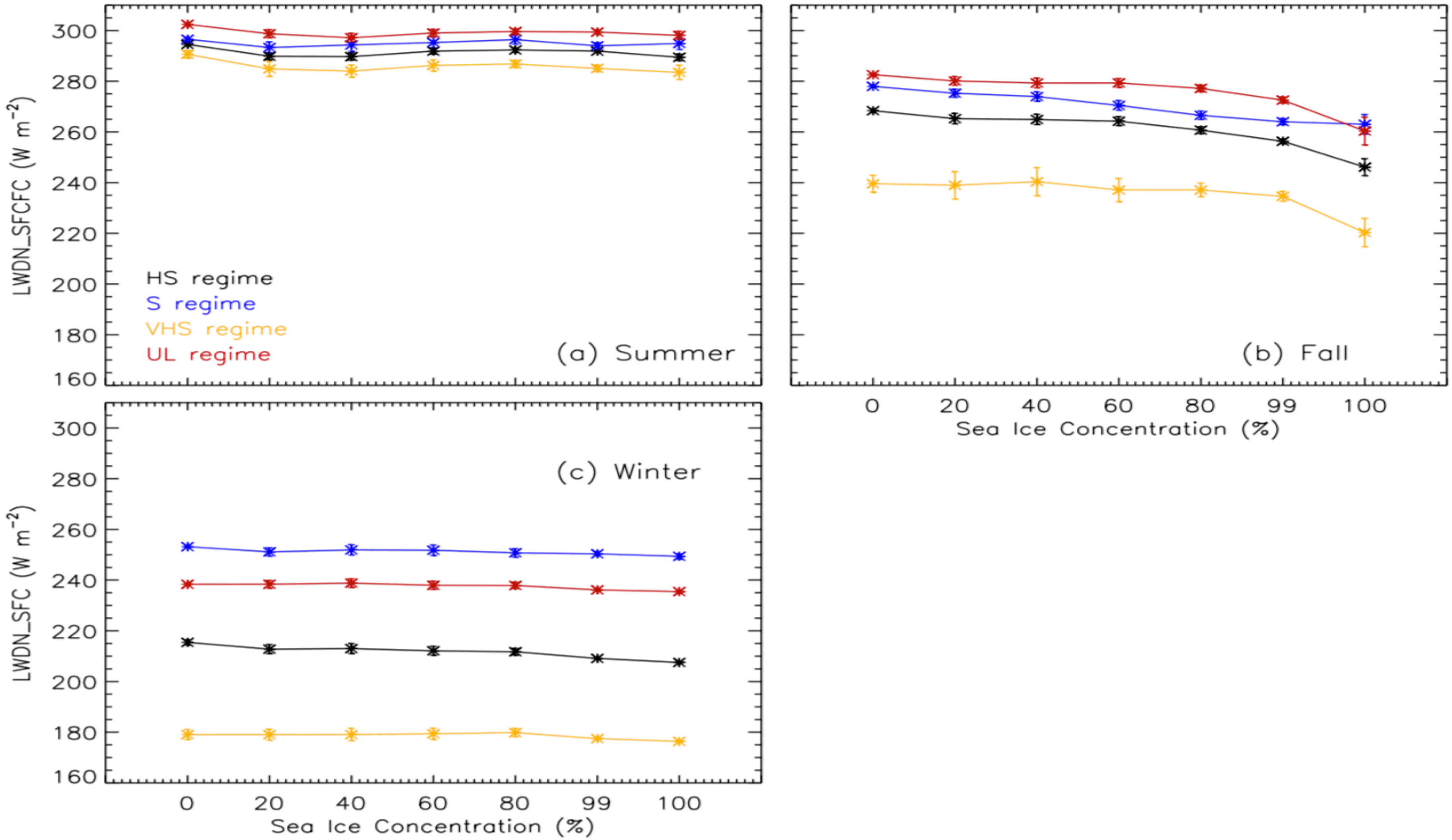
In Autumn, statistically significant decreases in cloud fraction (CF) and LWP are found.

- CF decreases by 2-3% between 0 and 100% sea ice concentration.
- LWP decrease by as much as 10 g m^{-2}



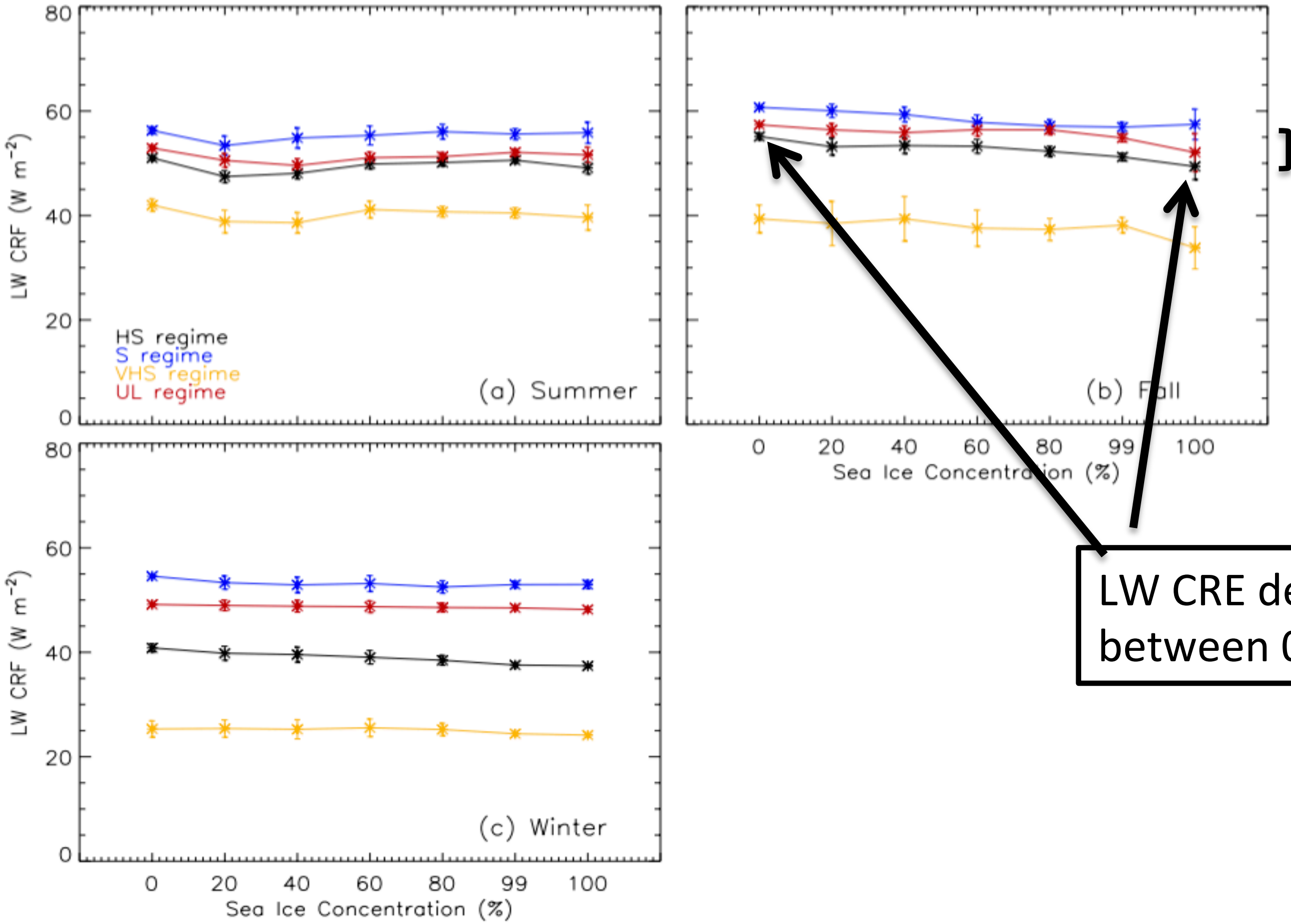
The HS regime exhibits, the largest magnitude covariance between cloud properties and sea ice.

Results: Surface Downwelling LW flux



- General decrease downwelling longwave flux at the surface with increasing sea ice.
- Statistically significant differences at the 95% confidence interval are found in fall for all regimes.

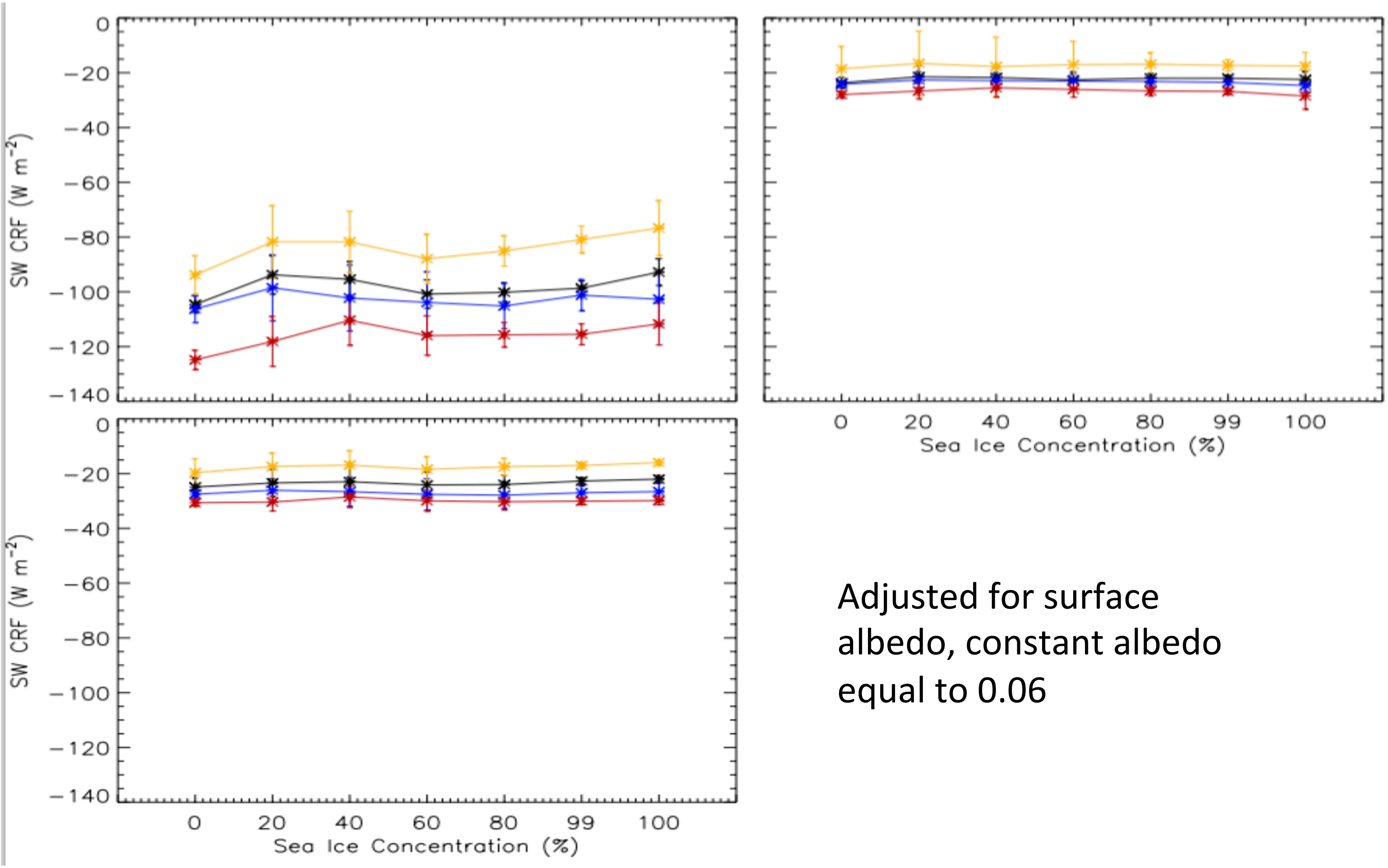
Results: Surface LW CRE



LW CRE decrease by 5 W m^{-2} between 0% and 100% SIC.

- General decrease in the LW CRE at the surface with increasing sea ice.
- Statistically significant differences at the 95% confidence interval are found in fall for the HS and S regimes.

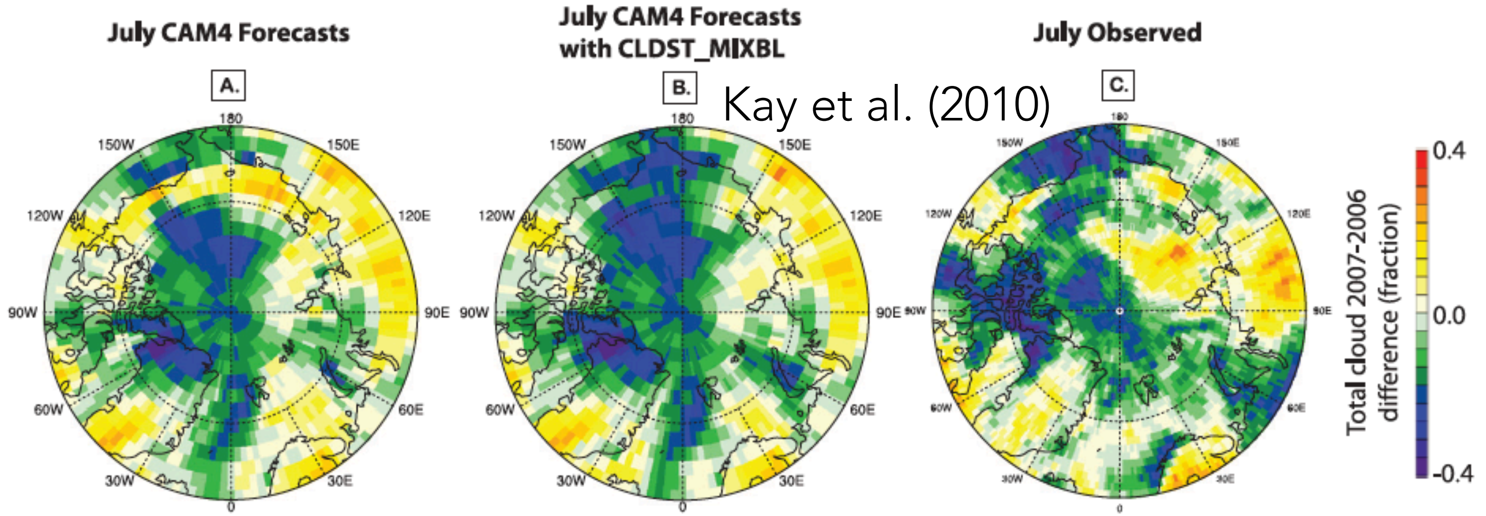
Results: Surface SW CRE

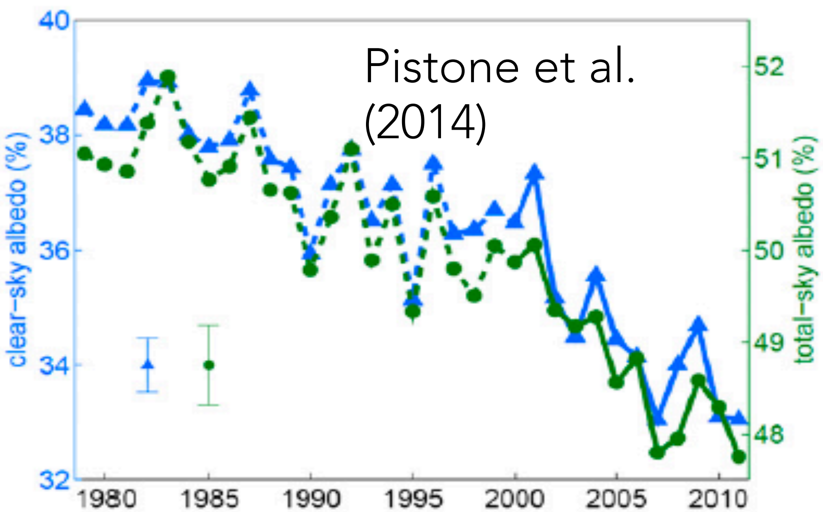


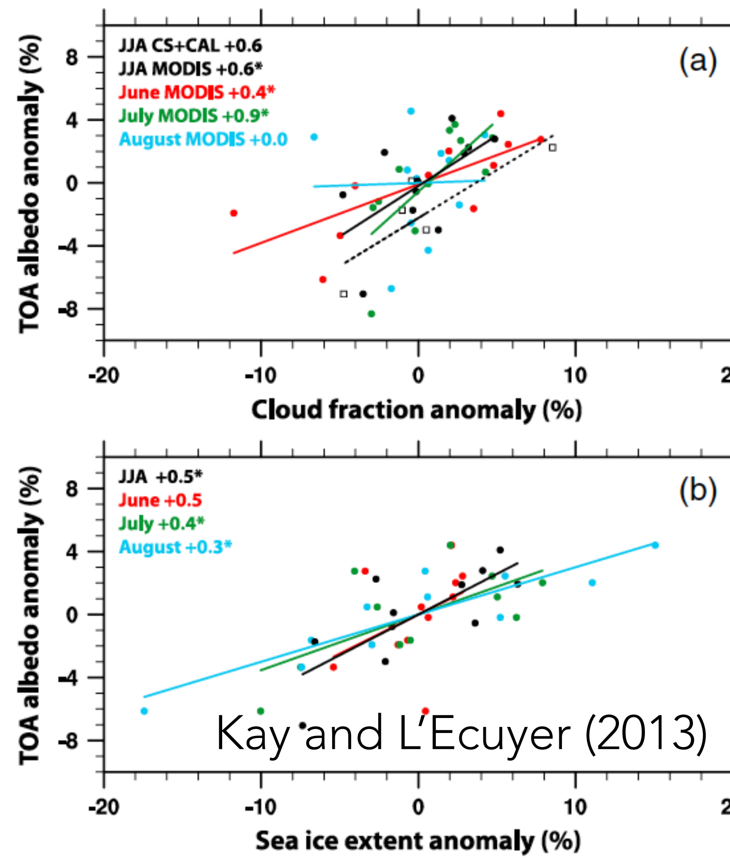
Adjusted for surface albedo, constant albedo equal to 0.06

- Generally less negative SW CRE at the surface with increasing sea ice.
- No statistically significant differences around found at the 95% confidence interval.

Post-game analysis—Sea ice dominates!?







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